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The Meteorological Magazine

December 1992

Analysis of intense mid-latitude cyclones

Noctilucent clouds 1991

GCOS Report

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The Meteorological Magazine

December 1992
Vol. 121 No. 1445

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Synoptic and mesoscale analysis of intense mid-latitude cyclones

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Summary

Surface observations together with radar and satellite imagery are used to identify the subsynoptic-scale air-mass structure of an intense cyclonic storm that crossed the British Isles on 16 October 1987. Comparison of their characteristics with those of a number of more recent intense cyclonic storms indicate a number of common features.

1. Introduction

The intense depression that crossed southern Britain during the early hours of 16 October 1987 will be remembered mostly for the exceptionally strong surface winds and enormous damage to the tree population of the area. However, meteorologically, several other notable events occurred:

(a) A sharp warm front preceded the depression with temperatures rising by up to 10 °C in places during its passage.

(b) Within the warm air, several distinct and sometimes sudden changes of temperature and/or dew-point occurred.

(c) Behind, and on the eastern flank of the low, the transition back to cold air was, in some places, very sharp whilst at other places gradual.

(d) Very large pressure rises were recorded immediately behind the low.

The first part of this paper seeks to explain these events within a synoptic context using surface observations, autographic records and radar rainfall and satellite imagery. Later, important similarities between the structure of this storm and those of more recent storms are identified.

2. The storm prior to arrival over Great Britain

Although this paper is mainly restricted to the weather of 16 October 1987 over the British Isles, clues to the synoptic structure of the storm in the twelve hours or so before its arrival over Britain were gained from satellite imagery supported by surface observations. The surface analysis at 1500 UTC 15 October 1987 (Fig. 1(a)), showing two roughly parallel fronts, has been drawn with considerable weight given to satellite imagery (Fig. 2). Front 'F', associated with a cloud band 'X' had been in existence for upwards of 24 hours, whilst a newly formed front, 'P', has been drawn within low cloud at the forward edge of a cloud area labelled 'Y' in the NOAA infrared image shown in Fig. 2. The centre of the surface low that developed into the storm is located close to front 'P'.

Subsequent movement of front 'P' was determined by tracking the forward edge of cloud area 'Y' using a movie-loop of Meteosat infrared images. This cloud edge became increasingly curved with a tongue of low cloud being drawn round the low to its eastern flank (Fig. 3). By 2200 UTC the cloud pattern had become too ill-defined for further tracking.

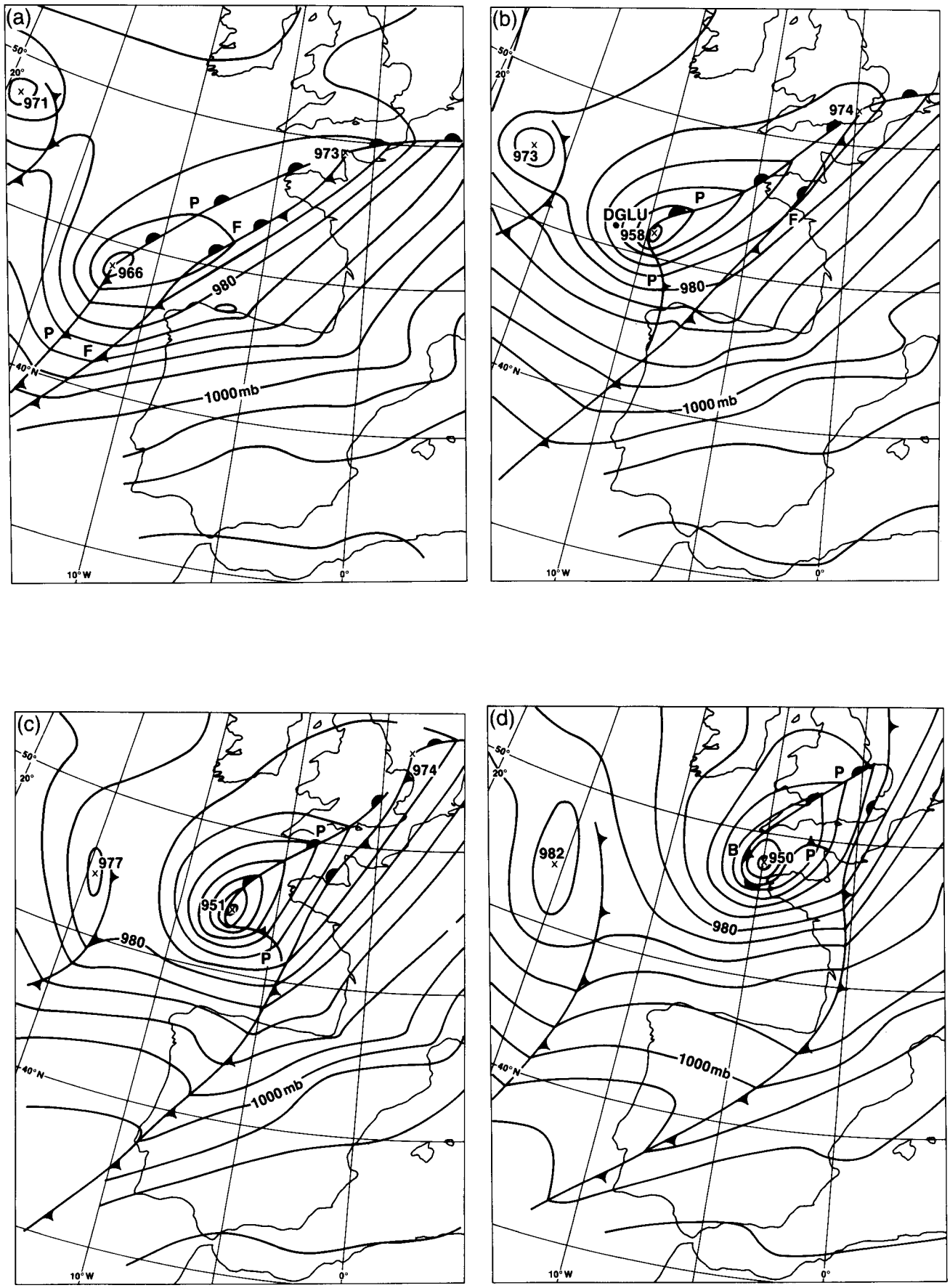


Figure 1. Surface analyses at (a) 1500 UTC on 15 October 1987, (b) 1800 UTC on 15 October 1987, (c) 2100 UTC on 15 October 1987 and (d) 0000 UTC on 16 October 1987. The position of ship DGLU at 1800 UTC is shown in (b).

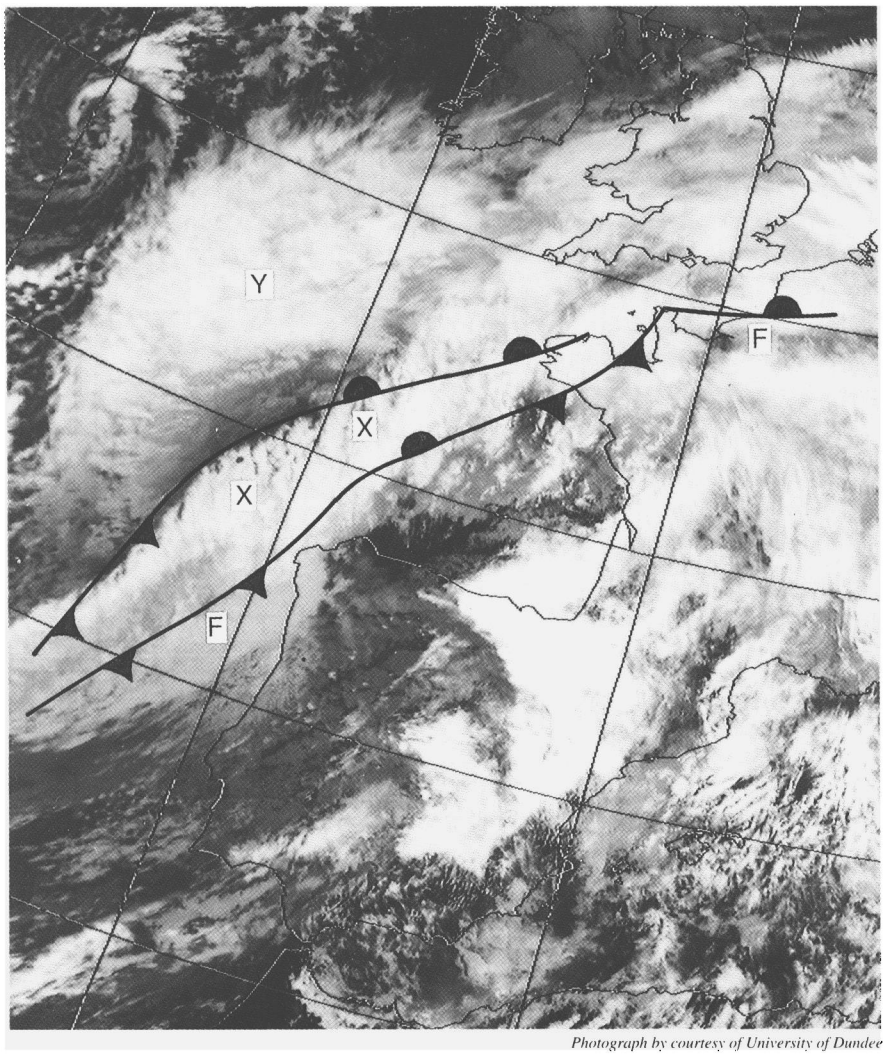


Figure 2. Infrared satellite image at 1450 UTC on 15 October 1987 showing the relation between cloud features and surface fronts. Front 'F' is associated with the cloud band 'X', and front 'P' with cloud area 'Y'.

The movement of the low was also determined using the satellite movie-loop. Its position was estimated as being at the centre of rotation of fragments of low cloud. This placed the track west of the synoptic analyses shown in Woodroffe (1988) who carried out a reanalysis immediately after the storm, but is in close agreement with that of Jerraud *et al.*(1989). Although the low-level rotation centre of low cloud is not necessarily coincident with the isobaric centre (see later text), it was considered a reasonable guide.

The only other evidence of the low position at 18 UTC came from a single nearby ship observation, which unfortunately contained errors. Ship DGLU, (position located in Fig. 1(b)) reported a pressure of 978.5 mb having apparently risen by 9.5 mb in the previous 3 hours. However, the ship's previous observation 6 hours earlier reported a pressure of 988.0 mb, exactly 9.5 mb higher than that observed at 1800 UTC. The 1200 UTC pressure had been flagged as incorrect by the Meteorological Office Central Forecasting Office since it was approximately 10 mb higher than a cluster of adjacent ships. It is assumed that at 1800 UTC, its reported pressure remained 10 mb too high, that in the pressure tendency group the apparently rising pressure should have been falling and the tendency period was between observations, namely six hours, and not the normal three hours. None of these errors are unprecedented in ship observations.

Further deepening of the low occurred during the evening (Fig. 1(c)), and by midnight 16 October (Fig. 1(d)), the low had reached its deepest, 950 mb just off Brittany. Jerraud *et al.* (1988) show the barogram trace from Brest at the western extremity of Brittany, north-west France dipping slightly below 950 mb just before midnight.

3. The storm over Great Britain

The surface low reached southern Britain during the early hours of 16 October. In order to obtain a detailed surface analysis during this period, all surface synoptic reports for southern Britain between 0100 and 0500 UTC inclusive were compiled onto a single map, nominally for

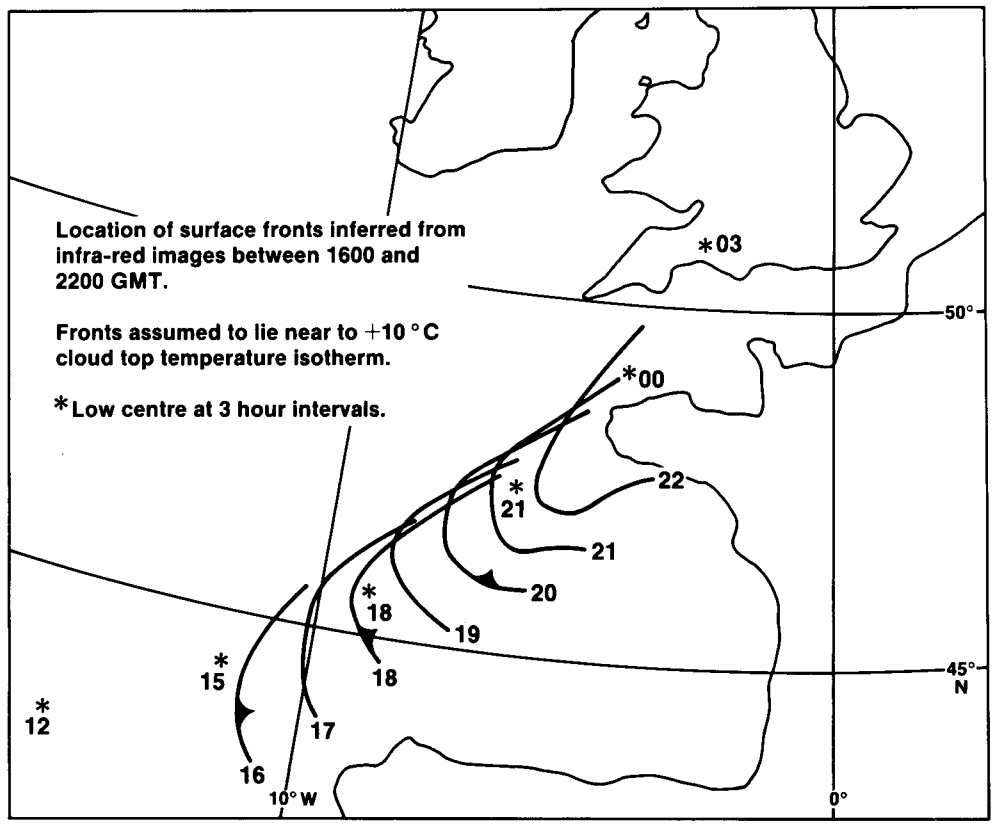


Figure 3. Positions of front 'P' at hourly intervals derived from the movement of a band of low cloud at the leading edge of cloud area 'Y' (see Fig. 2) and, at 3-hourly intervals, the position of the low centre (denoted by asterisks). Positions of the low at 1800 and 2100 UTC are based on imagery.

0300 UTC, by displacing observations recorded before or after 0300 UTC according to the velocity of the low during the period, i.e. 215° 48 kn. The advantage of the method was that in the rapidly changing conditions, 'rogue' observations, taken a few minutes away from nominal observation time were easily identified within the large field of observations. Exposed coastal stations which tended to experience stronger mean winds and higher temperatures also stood apart.

Fig. 4 presents the results, showing in Fig. 4(a) aspects of the surface weather and in Fig. 4(b) the frontal and air-mass analysis. Most air-mass boundaries are seen to be related to a strongly contorted front, shown later to be front 'P'. For ease in the following discussion, air on the cold side of front 'P' (originating west and north of the front) is labelled air mass 1, and that on the warm side air mass 2.

Strongest temperature and dew-point gradients occurred on the northern and western flank of the storm. Ahead of the storm, air mass 2 advanced slowly north, temperatures typically rising around 8 °C within about 30 minutes. On the southern and eastern flanks of the low, the thermal contrast between air masses 1 and 2 progressively decreases, although a marked dew-point discontinuity persists. The analysis also suggests that on the eastern flank, the returning air mass 1 (labelled 1M) has advanced around the low so as to begin to cut-off a 'warm-core seclusion', a region of moist and relatively warm air near the vortex centre (labelled 2S). The term seclusion was first used by Bergeron, but has recently been adopted by Shapiro (1989) in describing warm cores of intense cyclonic storms off the eastern seaboard of the United States.

The eastern and northernmost boundary of air mass 1M has been labelled a cold front although the temperature falls little despite distinct humidity change. Rather, the passage of the front marks the onset of a period of sustained temperature fall. The front was also accompanied by a band of showers which were identified by radar. Fig. 5 shows the 0130 UTC picture, when the showers were near the centre of the radar area. The speed and direction of travel of the shower band derived from a succession of radar images suggested it to be the advancing front 'P' identified approaching Brittany 3 hours earlier using the satellite movie-loop.

Within air mass 1M and also in that part of air mass 2 labelled 2M in Fig. 4(b), certain stations reported particularly dry air, although according to the analysis in Fig. 4(a), its structure was incoherent. However, Meteosat infrared and water vapour imagery at the time (not shown) indicated a tongue where cloud was confined to very low levels, with extremely dry air aloft. Although no radiosonde ascent sampled this air, it is most likely that in the strong low-level winds, patches of dry air

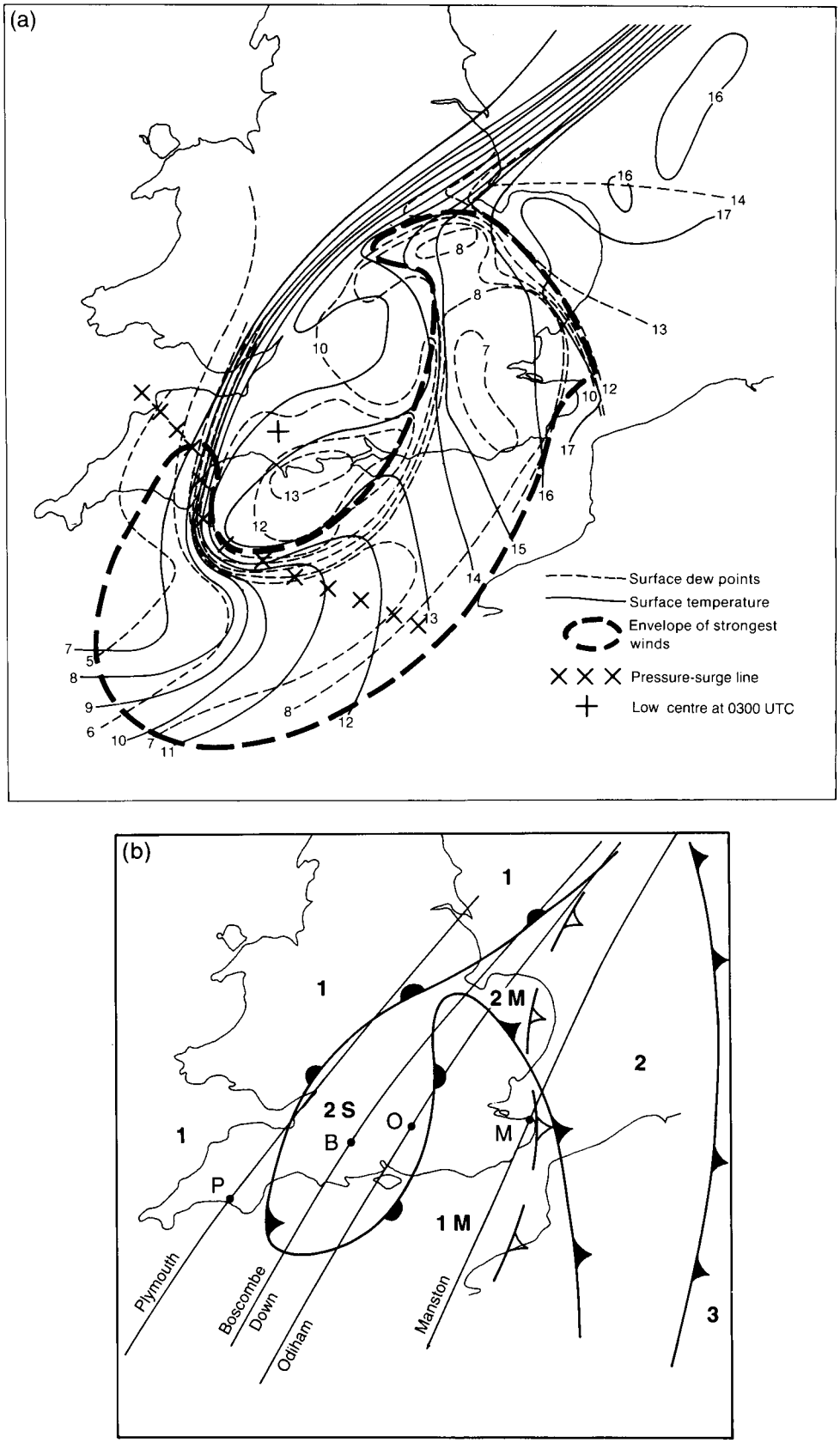


Figure 4. (a) Detailed surface analysis of the storm at 0300 UTC on 16 October 1987, based on all observations between 0100 and 0500 UTC (data before or after 0300 UTC are plotted relative to the 0300 UTC data by moving according to the system velocity of 215° 48 kn). (b) Locations of fronts and air masses derived from the analysis in (a). Air mass 1 refers to the cold air mass, 1M being modified cold air being drawn around the right flank of the low. Air mass 2 is the warm air mass, region 2M has been modified by the presence of very dry air, and 2S is the warm-core seclusion. (c) (overleaf) Surface synoptic and wind analysis derived only from 0300 UTC observations. The centre of cyclonic rotation according to surface winds is indicated by arrows.

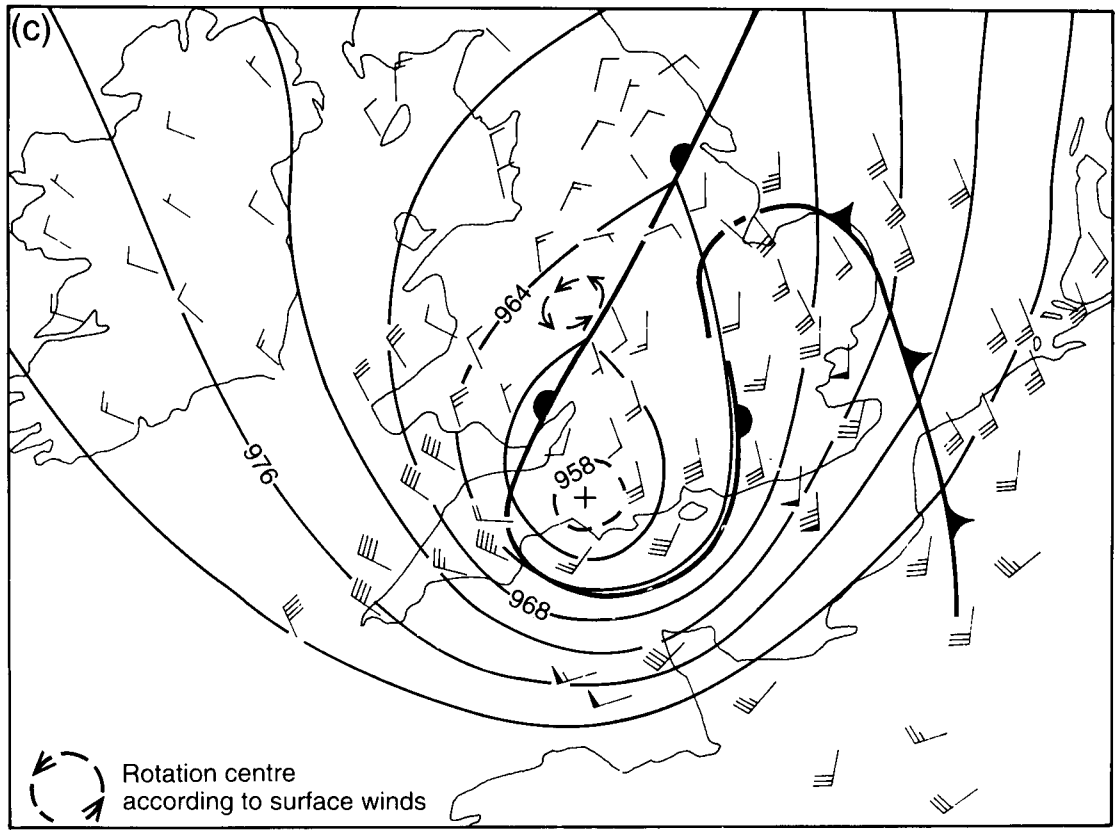


Figure 4. (Continued)

reached the ground, but since the tongue of dry air was moving at a different velocity to that of the low centre, it was not resolved in the analysis.

Reports of strong winds, mean winds of 45 kn or more and gusts of 60 kn or more all fell within a well defined curved envelope lying within air masses 1 and 1M. Another feature of the observations, rapid pressure rises, commenced along the line marked by crosses.

The isobaric analysis together with observed winds at 0300 UTC is shown in Fig. 4(c). The isobaric and wind circulation centres are not coincident, with southerly (ageostrophic) winds in the region of lowest pressure. The tendency for winds in the centre of a fast moving, intense low to blow along its direction of travel has been documented elsewhere. See for example Monk *et al.* (1987). Note that due to different analysis methods, there is a slight difference in the frontal positions shown in Figs 4(b) and 4(c).

4. Autographic records

Further support for the analysis was obtained from a study of around 60 sets of autographic records of temperature, humidity, wind and barometric pressure obtained from locations within Great Britain. Each record was initially checked for timing errors, this being done independently of this study. Any errors were noted. Records were then scrutinized in order to identify significant meteorological events. A sample from four sets of records, chosen to form a west to east section across southern England are described here.

Figure 5. Precipitation at 0130 UTC on 16 October 1987 at the cold-frontal boundary separating air mass 2 from the advancing air mass 1M derived from the UK rainfall radar network. Precipitation remote from the front has been excluded

Fig. 6 shows the thermograph and hygrograph traces for Plymouth, in the west of England (labelled P in Fig. 4(b)). Although lying mostly within the cold air mass 1, for 2 hours this was replaced by the warm core

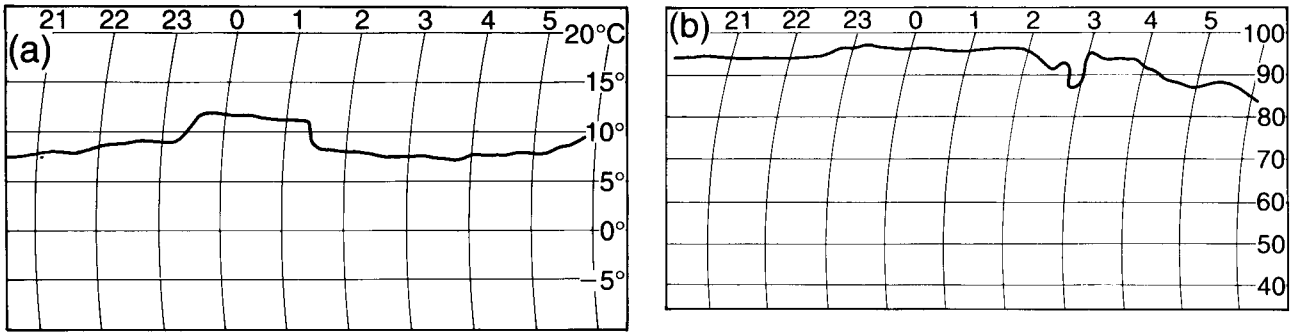


Figure 6. (a) Thermograph and (b) hygrograph records for Plymouth on 15/16 October 1987.

seclusion (air mass 2S), when the temperature increased by 4 °C. At Plymouth, both air masses were nearly saturated.

Boscombe Down (labelled B in Fig. 4(b)), lay very close to the storm track, the isobaric centre passing just to the west. Its records are shown in Fig. 7. As at Plymouth, the arrival and final departure of air mass 2 is marked by sudden temperature rise and fall respectively (observed at 2230 and 0430 UTC in Fig. 7(a), the final temperature falling back to its initial value. However, the relative humidity trace (Fig. 7(b)) shows considerable fluctuation. One hour after arrival of the warm air (air mass 2), the humidity began to drop; the fall commencing with the arrival of the dry air aloft indicated by satellite imagery. The fall in humidity was temporarily halted at 0030 UTC, when the band of showers shown in Fig. 5 passed, and air mass 1M arrived. Between 0130 and 0200 UTC the air at Boscombe Down returned to saturation with some drop in temperature as the warm-core seclusion, air mass 2M, arrived. Following return to the cold air mass 1, the humidity began to drop.

The wind record (Fig. 7(c)) shows two distinct periods of strong winds, occurring just after 0100 and 0430 UTC separated by a lull coinciding with the warm-core seclusion (air mass 2M). Maximum gusts were recorded immediately before and after the lull. The barogram record (Fig. 7(d)), shows a steady and sustained fall of pressure until 0300 UTC. After a short steady period, pressure began to rise extremely rapidly — nearly 25 mb in the next 3 hours. The pressure rise began just before the departure of the warm core, ahead of the pressure-surge line shown in Fig. 4(a), the discrepancy being due to the line in Fig. 4(a) being derived only from hourly ynoptic observations.

Fig. 8 shows the thermogram and hygrogram for Odiham (O in Fig. 4(b)), located just east of Boscombe Down. The temperature rose 8 °C at 2200 UTC, accompanied by a fall in humidity as air mass 2 arrived. A temporary rise in humidity and onset of period of falling temperatures occurred as the shower band passed at about 0100 UTC. A small temperature rise accompanied the arrival of the warm core (0245 UTC), followed by the usual sharp fall to its initial value with the return of air mass 1 at 0430 UTC.

Finally, Fig. 9 shows the thermograph (a) and hygrograph (b) record for Manston. Unfortunately, both records were judged to have timing errors and considerable blotting of the temperature trace occurred during the windiest part of the night. The timing error on the humidity record approached 90 minutes, but the error was known to the local observer who later annotated and reset the chart. For ease of reference, the traces have been redrawn with corrected timing. Once again, the same features were observed, except that Manston never experienced the warm core. Air mass 1M arrived at 0240 UTC accompanied by the familiar temporary rise in humidity and a sustained period of temperature fall.

Earlier in the night, other air-mass changes were shown in the records for Manston that were not observed elsewhere. Although not carefully analysed, they were judged to be related to the advance and retreat of frontal zone F which affected only extreme south-east England.

5. The warm-core seclusion and bent-back warm front

A well organized curved band of cloud and rain, best seen at 0500 UTC (Fig. 10) when the rain was situated near the centre of radar coverage, lay around the periphery of the warm core. Only on the eastern flank of the low were both cloud and rain either absent or disorganized. South of the low centre, middle- and upper-level cloud and general rain terminated abruptly within a sharply curved 'hook-shaped' region. The hook was located within the rearward (western) part of the envelope of strongest surface winds shown in Fig. 4(a). Movie-loops of both satellite and radar data indicated that the cloud/rain system and hook location moved with the system velocity and hence remained tied to the region of strong winds and the warm core. There was also strong indication that cloud and precipitation elements moving from the west into the hook underwent decay, suggesting air-mass descent.

Since the air near the low centre was of warm origin with very marked thermal change north and west of the low, its boundary has been marked in Fig. 4(b) as a warm front (apart from a small part of the front travelling 'the other way' and hence marked as a cold front). The radiosonde ascent for Camborne in south-west England at

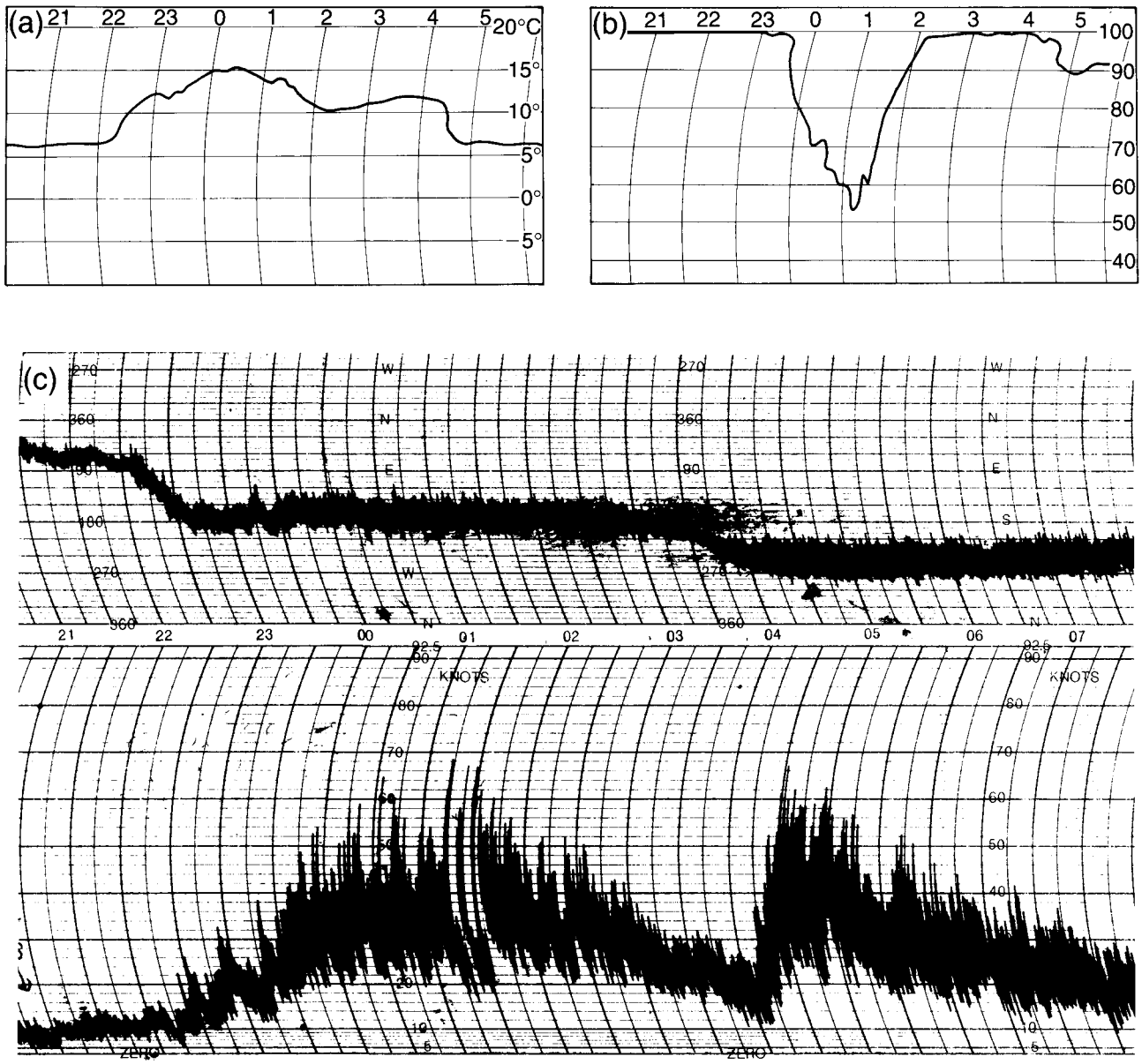


Figure 7. (a) Thermograph, (b) hygrograph, (c) anemograph and (d) barograph records for Boscombe Down on 15/16 October 1987.

0000 UTC on 16 October 1987 sampled low-level air just west of the front, ahead of the warm core (Fig. 11). A sharp frontal inversion is observed at 850 mb, beneath which winds increase rapidly toward the ground indicating a reversed thermal wind gradient confirming the presence of warm air toward the low centre. Since the warm front is curved around the low, it maybe referred to as a 'back-bent warm front' rather than the traditional back-bent occlusion. Shapiro (1989) first refers to back-bent warm fronts in association with intense cyclonic storms.

During the winters that followed the October 1987 storm, a number of intense cyclonic storms either crossed or passed near to Britain. A study of each storm revealed a number of features in common with the October 1987 storm. Their overall weather distribution and frontal structure are summarized in Fig. 12, and three of the cases are discussed briefly in section 6. The key features common to the storms are:

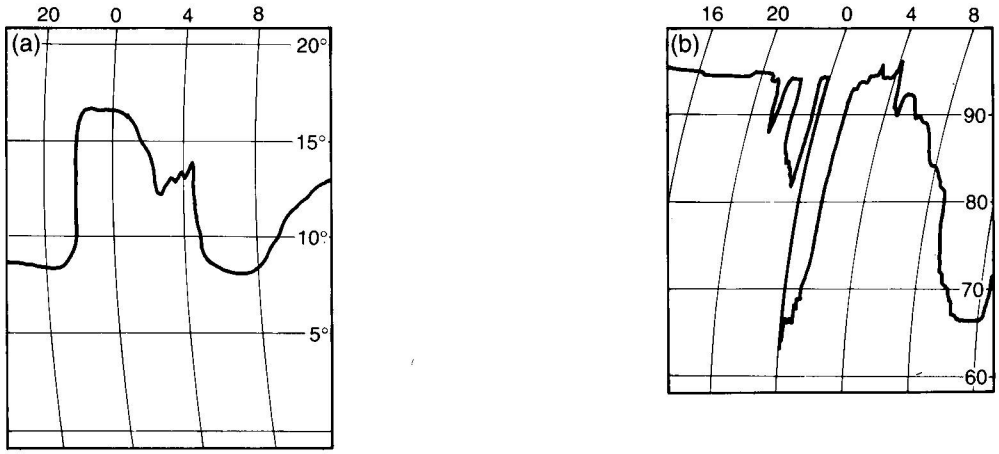


Figure 8. (a) Thermograph and (b) hygrograph records for Odiham on 15/16 October 1987. The hygrograph record is approximately 1 hour slow.

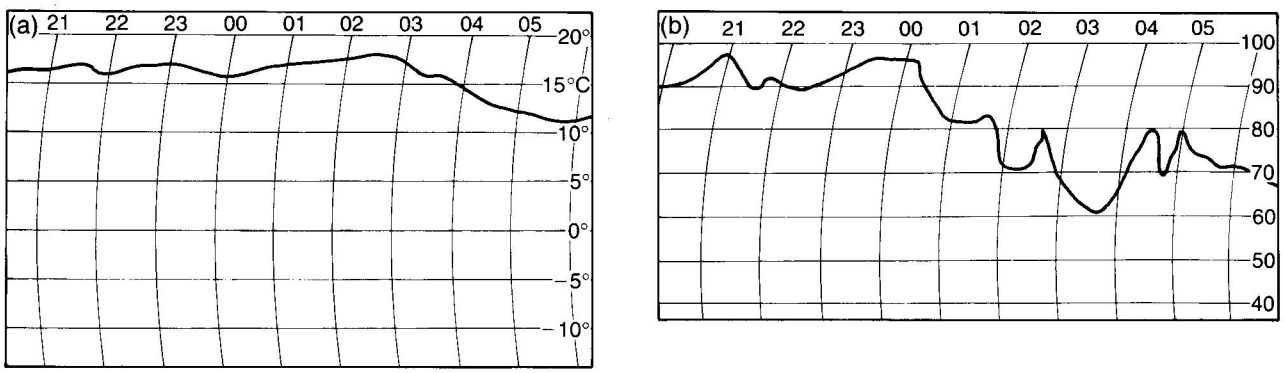


Figure 9. (a) Thermograph and (b) hygrograph records for Manston on 15/16 October 1987. Both records had timing errors and have been redrawn (see text).

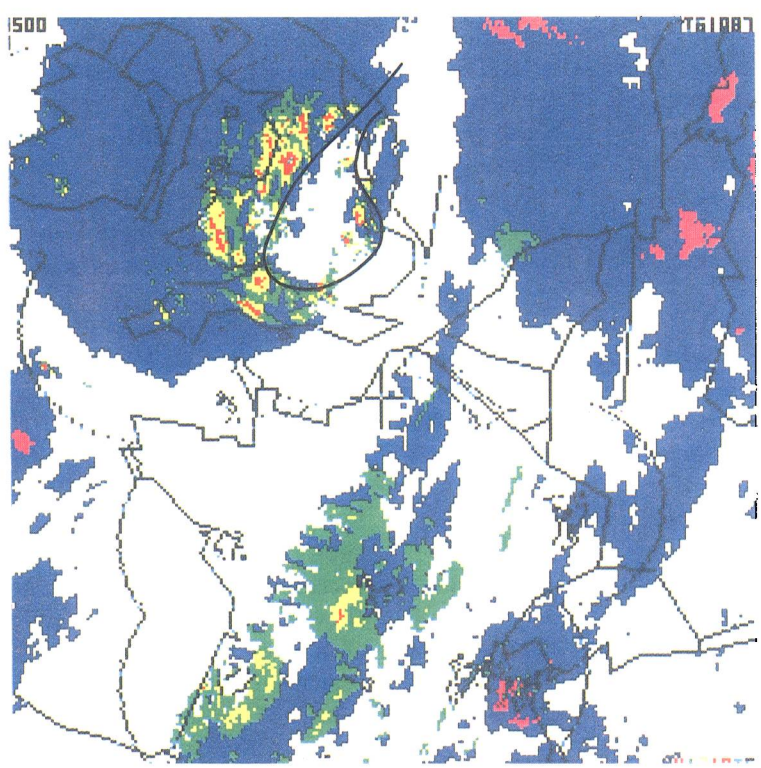


Figure 10. Satellite and radar (COST-73 network) at 0500 UTC on 16 October 1987. The blue and pink areas represent temperature ranges in the infrared, pink representing the coldest cloud tops, whilst the green, yellow, red and blue represent increasingly intense precipitation as measured by weather radar. The location of the back-bent warm front is superimposed.

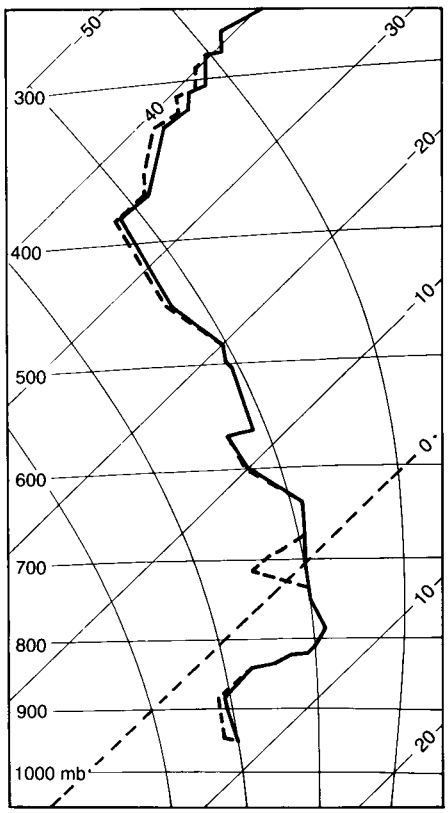


Figure 11. Tephigram for Camborne, south-west England, at 0000 UTC on 16 October 1987.

(a) Each have a warm core.
(b) The warm core is either partly or totally secluded, that is cut off from the main region of warm air.
(c) A sharp temperature contrast exists on the left flank of each low at the boundary of the warm core suggesting a back-bent warm front. North-west of each storm, there is often a region of particularly low temperature in the cold air adjacent to the back-bent warm front.
(d) A curved region of strong winds lies just outside the warm core.
(e) A broad band of thick cloud and rain partly surround each warm core. Thickest cloud and rain usually terminate abruptly within a hook-shaped region on the right flank (usually southern side) of each low, collocated toward the upwind limit of the region of strong winds.
(f) Very rapid rises of pressure set in behind each low.

Generally, there was some evidence of a double frontal zone and, according to water vapour imagery, there was often a tongue of extremely dry air aloft. On more than one occasion the pattern of rainfall at a secondary cold front strongly resembled the convective streets shown in Fig. 5. Very rapid pressure rises set in behind each low, the strongest rises being found in the region of the cloud/precipitation hook. Typically, immediately behind each low, beneath the area of cloud and rain, surface isobars converged, with the tightest isobaric gradient beneath the cloud/precipitation hook.

6. Comparison with other intense cyclonic storms

The major characteristics of intense cyclonic storms at or toward the end of the deepening phase are shown for a small sample of cases using only a single surface synoptic analysis supported by temperature and dew-point observations and imagery. In each case, the weather conforms to the schematic model shown in Fig. 12.

6.1 8 November 1989

This was the least intense storm discussed here, although as the deepening low reached eastern England reported gusts of wind approached 70 kn. The warm core was particularly small, and there had been some evidence of multiple fronts (a second warm front is shown in Fig. 13(a)). Strongest thermal gradient is present at the back-bent warm front on the left flank of the low. The infrared satellite image (Fig. 13(b)) and the UK weather radar image (Fig. 13(c)) clearly show a sharp hook (H), located near the upwind limit of the region of strongest winds and a broad band of cloud and rain associated with the back-bent warm front toward the left flank of the low.

6.2 25 January 1990

On 25 January 1990, a core of hurricane-force winds crossed southern Britain and the near Continent. Severe damage occurred, and news reports suggested that the loss of nearly 100 lives could be attributed to the storm. Gusts of wind exceeded 80 kn over a wide area.

Once again, the moist warm core and back-bent warm front are clearly defined (Fig. 14(a)). West and north-west of the low centre, there was a temperature minimum within the cold air mass, resulting in rain turning to snow. Although not shown, a band of showers similar to those shown in Fig. 5 were observed as the second cold front crossed southern Britain. The convection was deeper than in the October storm, and accompanied by squalls with wind gusts almost as strong as within the main strong wind belt. The hook shown in the infrared image (Fig. 14(b)) is, at this time, not as well marked as in other cases, although it had been more distinct earlier.

6.3 3 February 1990

Although this depression was very shallow (988 mb) in comparison to most intense depressions, surface pressure gradients were very strong and gusts of winds exceeded 80 kn over northern France and later Germany. However, the warm core and back-bent warm front are clearly defined. At 1200 UTC, the bent back front has not penetrated as far round the depression as in the previous cases, and the core of strong winds is centred west of the low centre (Fig. 15(a)). A temperature minimum occurred west and north-west of the low centre, leading as in the previous case, to a temporary change of rain to snow. East of the low, the first cold front is not easy to

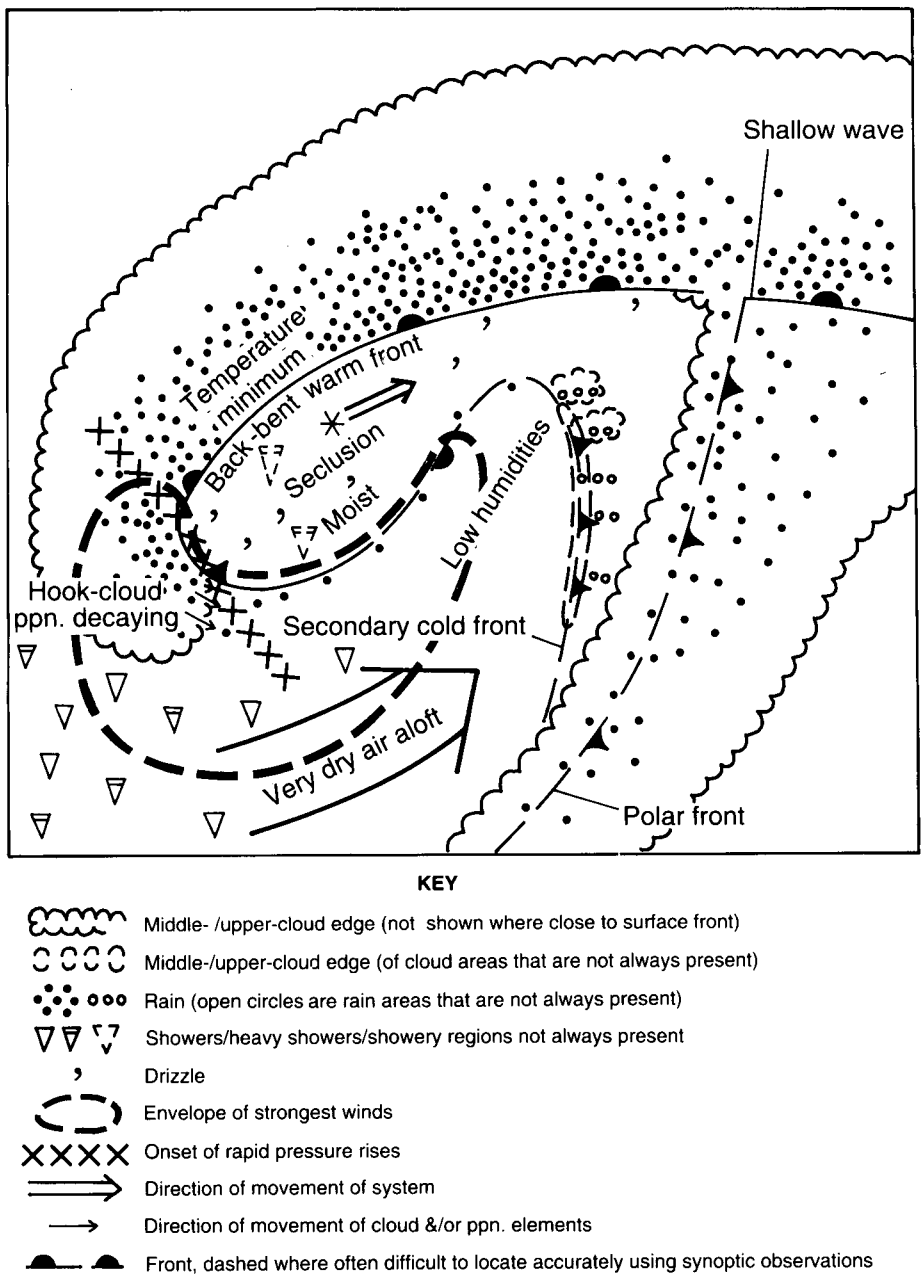

Shallow wave
Temperature minimum
Back-bent warm front
Seclusion
Moist
Low humidities
Hook-cloud ppn. decaying
Secondary cold front
Very dry air aloft
Polar front
KEY
Middle- /upper-cloud edge (not shown where close to surface front)
Middle-/upper-cloud edge (of cloud areas that are not always present)
Rain (open circles are rain areas that are not always present)
Showers/heavy showers/showery regions not always present
Drizzle
Envelope of strongest winds
Onset of rapid pressure rises
Direction of movement of system
Direction of movement of cloud &/or ppn. elements
Front, dashed where often difficult to locate accurately using synoptic observations

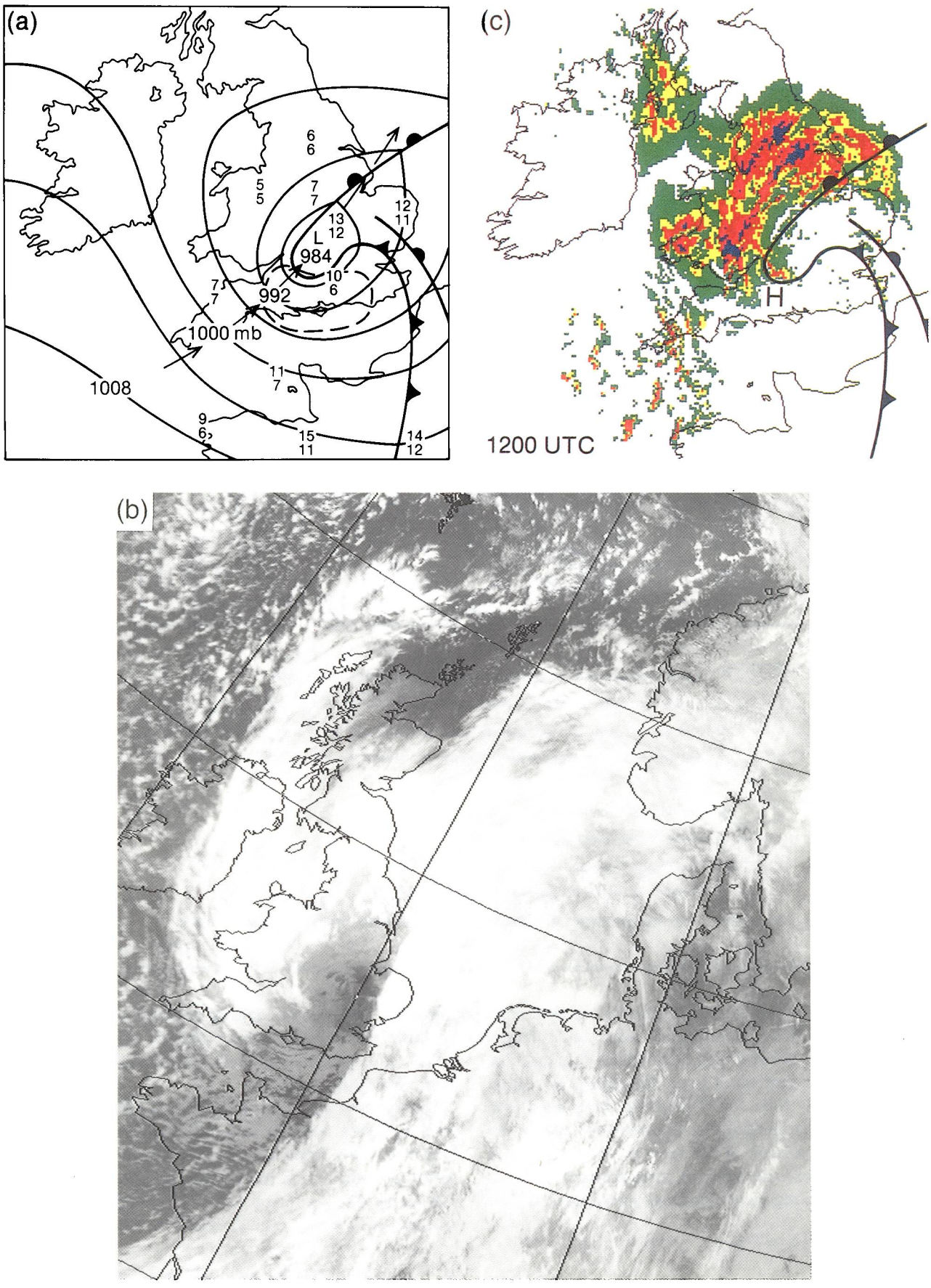
Figure 12. Schematic model showing the air mass and surface weather distribution within an intense mid-latitude cyclone.

locate due to relatively small temperature and dew-point changes. Fig. 15(b), a combined radar and infrared image, shows the broad region of cloud and rain associated with the back-bent warm front, although at this stage, there is relatively little curvature along the front. Cloud and rain terminate suddenly at the southern limit of the band, although a hook is not seen at this time. As in earlier examples, the band of strong winds extends forward from the region of cloud and precipitation decay.

6.4 Storm off the Pacific coast of the United States.

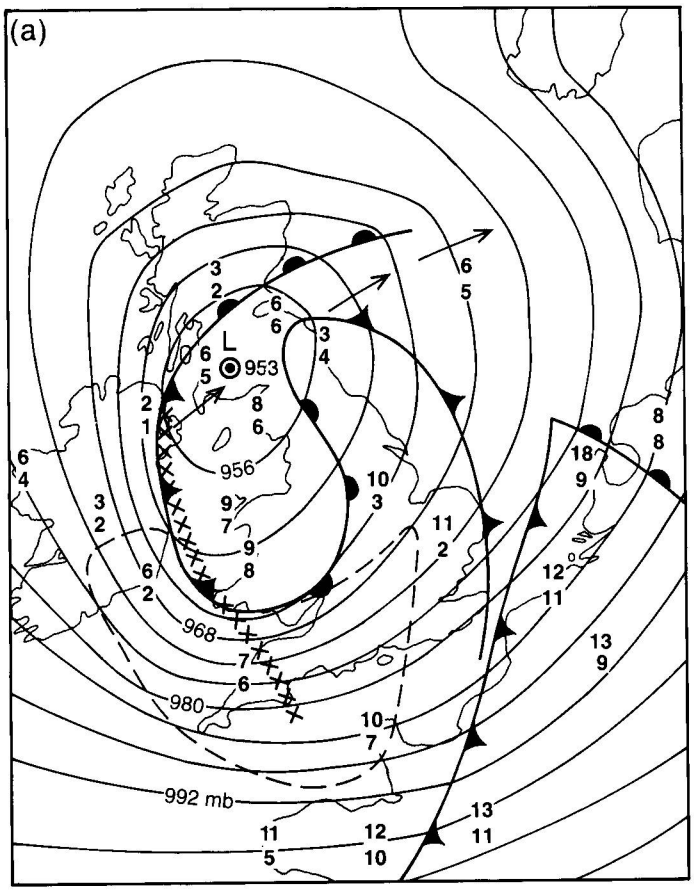
Fig. 16 shows a thermal analysis associated with an intense north Pacific storm investigated by Shapiro (1989) using aircraft measurements. There is remarkable similarity between this and the thermal structure of the October 1987 storm and those referred to above. In particular, strong thermal gradient locates a back-bent warm front west of the warm core.

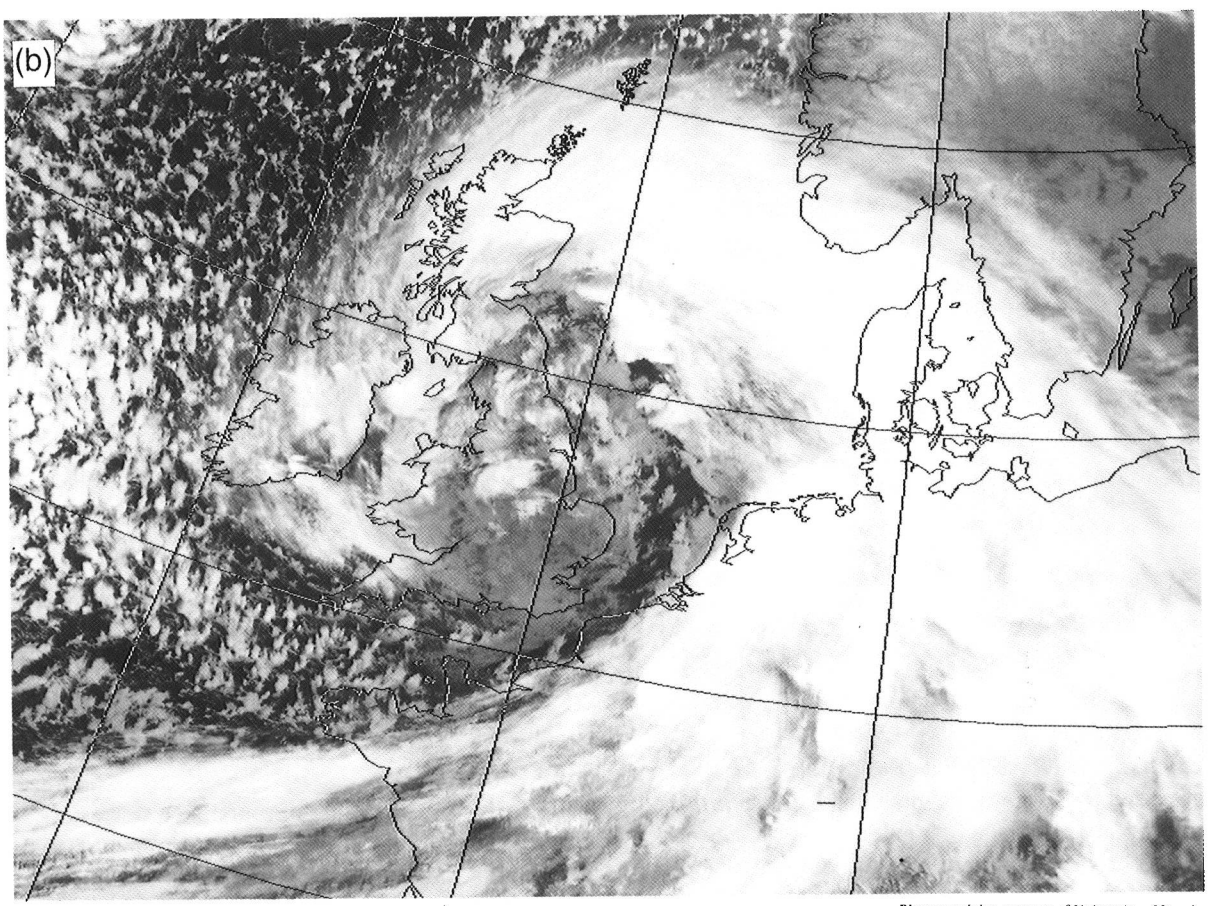
Routine synoptic analysis and inspection of imagery over the north Atlantic suggests that the formation of back-bent warm fronts are relatively common, sometimes forming within cyclonic circulations that are not as intense as those referred to here. A well documented example is shown in McGinnigle *et al.* (1988). The formation of a hook in the imagery occurs only during development of intense lows. However, whether a cloud hook is or is not present, middle and upper cloud terminates abruptly behind the surface low and strongest surface winds within the low circulation occur beneath



Photograph by courtesy of University of Dundee

Figure 13. (a) Surface analysis, showing dry-bulb temperature (upper figure) and dew-points (lower figure), (b) infrared image and (c) radar (UK network) at 1200 UTC on 8 November 1989.





Photograph by courtesy of University of Dundee

Figure 14. (a) Surface analysis at 1200 UTC; and (b) infrared image at 1324 UTC on 25 January 1990.

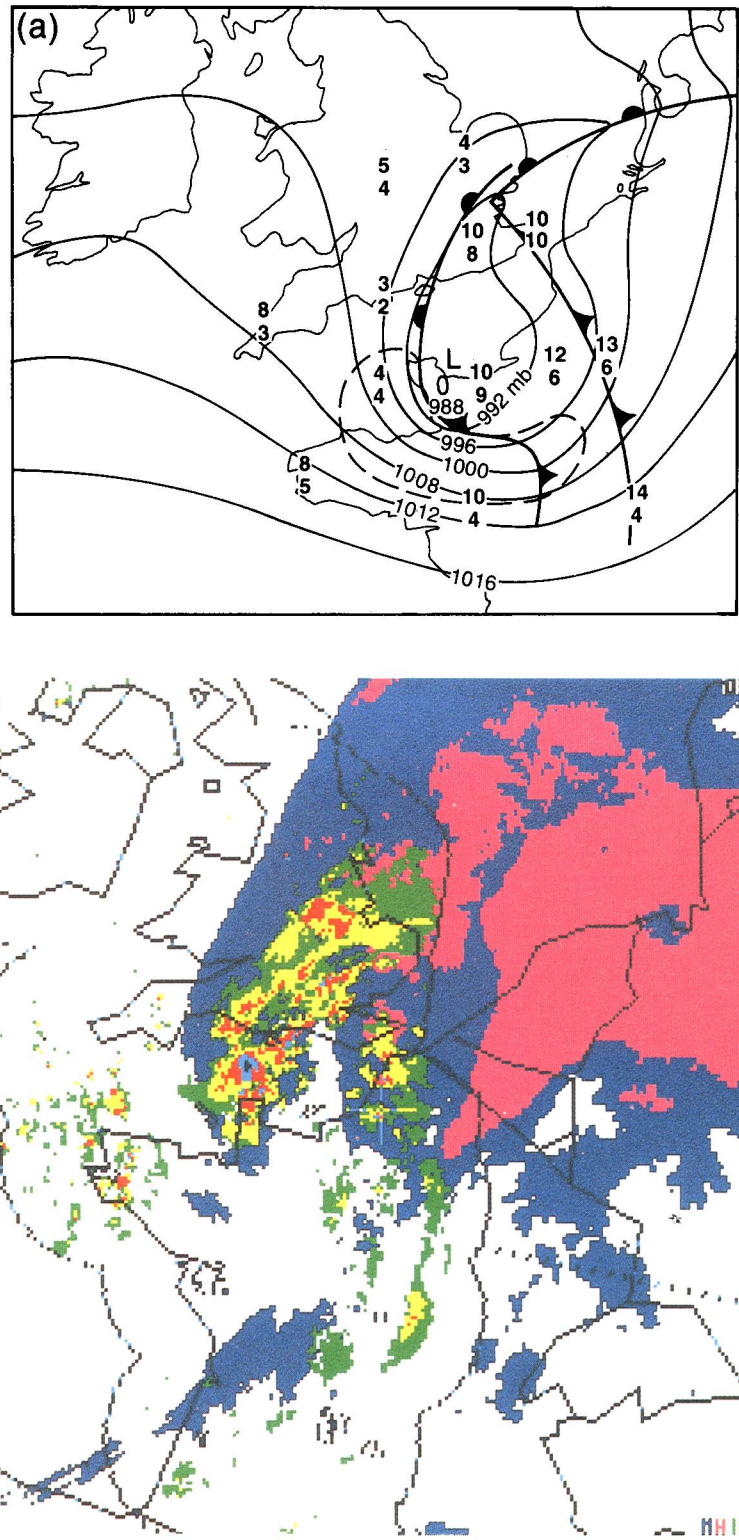


Figure 15. (a) Surface analysis, and (b) satellite and radar (COST-73 network) at 1200 UTC on 3 February 1990. Colours as in Fig. 10

the region of cloud dissipation. The most intense lows are characterized by a very broad cloud area at the back-bent warm front (ahead of, and on the left flank of, the surface low). The broad cloud area constitutes part of a cloud head (Böttger *et al.* 1975, Monk and Bader 1988) which forms during the early stages of cyclogenesis.

7. Conclusion

Back-bent warm fronts, surrounding a warm core and a curved zone of very strong winds are common to many developing and maturing intense mid-latitude oceanic cyclonic storms. These characteristics, including the approximate location of the strongest winds may be iden-

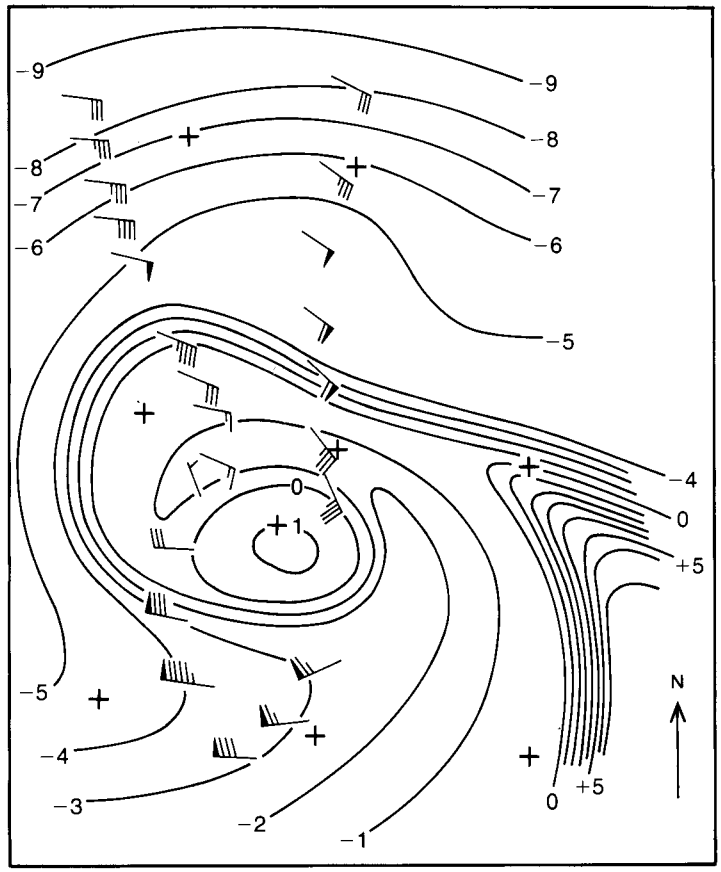


Figure 16. Temperature analysis (°C) at 850 mb of a warm-core seclusion situated in the Gulf of Alaska at 0000 UTC on 10 March 1987. From Shapiro (1989).

tified by synoptic-scale analysis and the use of satellite and/or radar imagery.

An operational forecaster analysing an intense low, may with the application of the model shown in Fig. 12, anticipate the regions of severest weather and make sense of quickly changing surface conditions even though he may not locate all the air-mass boundaries present. Satellite imagery is a particularly powerful tool, since major storms may be identified over the data sparse oceans, and regions of potentially damaging winds located.

The analyses also suggest that the traditional back-bent occlusion, should at least during the development stage of intense lows, be replaced by a warm front.

Acknowledgements

Grateful thanks to Doug Mansfield who painstakingly analysed the autographic records. Also to Glenn Shutts and Terry Davies for discussions regarding the nature of the warm core. Thanks also for the useful comments by Alistair Woodroffe and Martin Young on the draft version.

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551.593.653(4): 551.506.1

Noctilucent clouds over western Europe during 1991

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Summary

Noctilucent cloud observations by voluntary and professional observers in the British Isles, Denmark and the Netherlands suggest a low incidence of the phenomenon.

Table I summarizes the noctilucent cloud (NLC) reported to the Aurora Section of the British Astronomical Association (BAA) during 1991. The times (UT) are the reported sightings limits, not necessarily the durations of the displays. 'Negative' nights (Table II) are based on the judgement of two or more experienced observers north of 54° N with clear or nearly clear sky conditions over the period of the night when NLC is likely to occur.

Only 21 definite and 4 suspected NLC displays were reported but the summer of 1991 was beset by a great deal of tropospheric cloud. None of the bright, extensive displays characteristic of the late 1980s was seen, and some were so faint as to be recognizable only in binoculars by experienced and dedicated amateurs. Contributions were received from 19 individual observers and 5 meteorological stations in the British Isles, 2 observers in Denmark (Mr Olesen and Mr Andersen whose reports and photography were again of the highest class), and 3 stations of the Royal Netherlands Meteorological Institute. There is still a lack of response from the rest of western Europe. Details of Finnish–Estonian NLC sightings are published annually in the journal *Ursa Minor* of the URSA Astronomical Association (Laivanvarustajankatu 3, SF-00140, Helsinki 14). Details of individual NLC nights are available from the author, but all NLC data up to 1988 are held in the Balfour Stewart Archive at the University of Aberdeen.

Our thanks to all observers, amateur and professional, and to the following for their support and co-operation: Mr Ron Livesey (BAA Aurora Section Director), Mr Tom McEwan (Junior Astronomical Society Aurora Section Director), Mr Veikko Mäkelä (URSA, Finland), Dr Balthus Zwart (Netherlands), Mr Mark Zalcik (USA–Canada NLC Network) and Dr Michael Gadsden (University of Aberdeen).

Table I. Displays of noctilucent clouds over western Europe during 1991

Date — night of	Times UT	Notes
27/28 May	2300–2310	Silvery-blue billows and patches reported at Beauly, no NLC at Alness 2200.
31/01	0003–0150	Alness — no NLC 0015, 0130 small patches, 0140-0150 faint bands and billows, elev. at St Andrews 20°. Faint bands at Vildbjerg, Denmark, 0003–0045.
1/2 June	2345–0215	Faint bands in tropospheric cloud gaps at Vildbjerg, moderately bright bands and whirls at elev. 15°. Rønne, Denmark; bands and billows elev. 20° Rotterdam 0140–0215.
5/6	2230–0200	Rather faint bands and billows observed and photographed in central Scotland, max. elev. 15°. Faint bands and whirls Vildbjerg; all forms, faint, Rønne.
7/8	0110–0215	Faint diffuse bands at 12°, Glengarnock near Ayr.
10/11	0048–0245	Suspect faint bands at Glengarnock 0048–0100, with aurora 0041–0050. Billows in patches from 0205, elev. 60° Essex.
12/13 very	0050–0127	Billows and whirls to elev. 30°, Dundee, bands low at Pensarn, N. Wales, 0127.
13/14		Billows suspected with auroral arc, Upton-on-Severn.
15/16 June	2300–0245	Faint bands elev. 14°, Machrihanish, faint NLC suspected at Petworth, Sussex, from 0200.
16/17	2300–2315	Faint veil and patches suspected at Petworth.
21/22	2345–0015	Veil, bands and billows in trop. cloud breaks, Stirling.
22/23	2250–0300	Moderately bright, all forms, in patchy trop. cloud in Scotland, max. elev. Kinloss 24° at 2250. Extensive faint bands and billows photographed by Mr Peter at Carnoustie. NLC to elev. 15°, Rotterdam.
23/24	2205–2305	Suspected NLC at Appingedam, The Netherlands.
25/26	2300–0130	Moderately bright bands and billows, max. elev. 15°, central Scotland, Pensarn and Ronaldsway (Isle of Man).
26/27	0000–0212	Faint veil and bands at Glengarnock, max. elev. 25°, brighter and sharp 0145. Suspect NLC at Rotterdam 0000.
27/28	0120–0145	Suspect bands in haze, Glengarnock.
28/29	2250–0123	Faint veil, bands and billows at elev. 10°, Glengarnock. Faint veil at Pulborough, Sussex, 2250.

Date — night of	Times UT	Notes
2/3 July	0100	Moderately bright bands in haze, Arisaig.
4/5	2335–0015	Faint bands photographed at Vildbjerg.
7/8	2310–0115	Faint veil and bands, elev. 14°, Vildbjerg.
9/10	2315–0015	Very faint and poorly-defined bands/patches observed in binoculars, Glengarnock and Morpeth.
10/11	2130–0155	Faint veil, bands and whirls in trop. cloud gaps at Morpeth; patch of billow at Stambourne, Essex, 2200; bands and veil in evening twilight, Funen, Denmark; moderately bright bands, billows and whirls at Vildbjerg, max. elev. 44° at 0130, faded 0145.
12/13	0030–0100	Moderately bright whirls in trop. cloud gaps, Sumburgh, Shetland.
13/14 July	0020–0145	No NLC before 0000 Morpeth, then faint veil, bands and billows with auroral ray. Brighter bands, billows and whirls from 0045. At Musselburgh, Lothian, Mr Waldron saw brighter billows in trop. cloud 0100 and photographed auroral arc above faint bands 0111. Bands and billows in trop. cloud gaps, Glengarnock.
15/16	2130	Billows in trop. cloud gaps, Pulborough.
19/20		Dr Reid photographed NLC at Eigg.
20/21	2322–0230	Faint veil, bands, billows, some whirls, at Morpeth; brighter 0145, max. elev. 10°. Similar structures at Glengarnock, brightening 0015.
9/10 Aug.	0020–0115	Faint bands elev. 15°, De Bilt, The Netherlands.

Table II. Negative nights (British Isles) north of latitude 54° N.

May 24/25; 29/30; June 3/4; 4/5; 19/20; 20/21; July 5/6; 11/12; 28/29; 29/30; Aug. 11/12.

Conference Report

Seminar on the United Kingdom contribution to the Global Climate Observing System (GCOS), Houghton Lecture Theatre

The Office's new lecture theatre was officially opened by Sir John Houghton on 7 July 1992. The occasion was marked first by the presentation of the John Houghton Trophy for Weather Forecasting, to the Offshore forecasting team at Aberdeen, and then by a seminar on the UK contribution to GCOS which attracted a distinguished list of speakers and audience members. The theme of the seminar was particularly appropriate in view of the leading role that Sir John has played in initiating GCOS.

He described in his introduction how the recent UN Conference on Environment and Development in Rio had kept to the forefront concern about climate issues. Events such as Mrs Thatcher's celebrated 'green' speech to the Royal Society in 1988 and the setting up of the Intergovernmental Panel on Climate Change soon after, followed by its authoritative reports in 1990 and 1992, had also focused this concern, with the United Kingdom at the forefront of action. However, climate needs to be measured as well as modelled. Thus GCOS was conceived over lunch in Geneva during planning for the Second World Climate Conference (SWCC). Its birth was at SWCC, as a truly international activity. The need now is to put flesh on its bones, to produce a carefully thought out programme which can be convincingly argued and sold to the world's resource providers.

The first session considered GCOS in the context of climate prediction. Paul Mason (Met. Office) provided an overview summarizing why climate data are required. Thus, for monitoring and detecting change he stressed the need for data continuity and accuracy, and careful selection of the key variables. Observations are needed for demonstrating how well climate models can simulate present climate, and their credibility therefore in climate prediction; they are used also for model initialization, for example to describe the cryosphere and distribution of trace gas concentrations, and initial mean ocean state. He distinguished between deterministic predictability (scales ranging from a few days for atmospheric eddies, up to ENSO events) and statistical predictability (for mean climate and its variability). He noted that GCOS will underpin many process studies even though these may not be a central GCOS activity. The demanding requirements of a truly operational system which GCOS has to be were emphasized, for example in instrument technology and data processing.

John Mitchell (Met. Office) reviewed the data requirements for atmospheric models, from the perspectives of initial conditions, boundary conditions, conventional observations and new variables. He showed how substantially different initial temperatures perturb model predictions for only about a decade. The strong influence of ice-sheet extent on climate predictions was demonstrated, and the changes in heating rates over the last two cen-

turies following changes in trace gas and sulphate aerosol concentrations were described. He illustrated the requirement for sub-daily temperature and daily rainfall observations to validate the predictions of different climate models, and to verify model sensitivity to CO_2 concentrations. The sensitivity of models to cloud schemes and their feedbacks was stressed, and the use of satellite data to validate models and help constrain parametrizations of cloud properties was demonstrated. In summary, even though initial meteorological conditions were largely irrevelant, atmospheric data are needed for validation; boundary conditions are clearly required, as are the present conventional meteorological data, but new data requirements are emerging such as cloud water content.

Data needs for ocean modelling were described by Howard Cattle (Met. Office), distinguishing between predictions on century time-scales and seasonal time-scales. Model boundary conditions such as surface fluxes of heat, and their uncertainties, were reviewed. Large-scale or global ocean models reproduce many of the larger-scale features such as western-boundary currents. The use of tracers such as tritium as well as more conventional data (temperature, salinity) to verify models was described. Higher-resolution modelling is required to test whether ocean eddies need to be resolved or can be parametrized in coupled ocean–atmosphere models. The long time-scales of large-scale oceanic structure indicate that initial conditions are important for ocean modelling, unlike for atmospheric climate models. Coupling of models was briefly reviewed, with the possibility of regionally dependent modelling approaches when predictions are on short (e.g. interannual) time-scales. The overall data requirements were for surface fluxes and sea surface temperatures, large-scale ocean structure and variability, tracers, CO_2, nutrients and biology, and ocean eddy structure for key regions.

The second session, on measurement strategy, began with a review of space-based measurements by John Harries (Rutherford Appleton Laboratory). The advantages of space observations — global coverage, good calibration and multiplicity of measurements — are tempered by their limited spatial resolution, obscuration by clouds and precipitation, and cost; nonetheless, they have a major role to play in GCOS. Relevant current space-programmes such as the Upper Atmosphere Research Satellite (UARS), the Earth Resources Satellite (ERS-1) and the Earth Radiation Budget (ERB) were described, with examples shown of H_2O and NO_2 measurements by UARS, and sea surface temperatures from ERS-1. Future directions of the space programmes are under review in NASA and ESA at present. However GCOS requires an ambitious programme in order to monitor satisfactorily the composition, dynamics and energy balance of the atmosphere, and its clouds and precipitation.

Ground-based measurements were then discussed by Chris Folland (Met. Office). He emphasized the important role of radiosonde data in GCOS, and described problems with the existing networks; especially important are the decline in coverage in some regions, and disagreements between different radiosonde types. He showed how discontinuities in data series in recent years have been caused by the introducion of new sensors (e.g. rain-gauges in Finland; thermistor thermometers in USA), and how changes in measuring surface wind at sea had produced a varying bias. The role of mountain glaciers as monitors of climate change was mentioned. He concluded by stressing the vital need for homogeneity of past and future data for climate-change assessment.

The oceans are enormously important in controlling climate, and the more important issues here were presented by John Woods (NERC). Large-scale deep ocean circulations with their long time-scales for change are important for climate predictions decades or more ahead; near-surface circulations have important influences for the carbon cycle. Many of the currents are organized in narrow unstable jets near western boundaries and on the eastern side of bottom topography, and are difficult to measure routinely, or to model, because of the high resolution needed. The seasonal ocean boundary layer strongly influences atmosphere–ocean exchanges. Salinity structure (which cannot be measured from space) may change substantially over a few years in some areas, with consequent density changes. The measurement strategy for GCOS is to resolve the broad features at low resolution but to increase resolution in regions of intense jets and eddies; ship measurements will have to be vastly supplemented by fixed, drifting or motoring ('auto-sub') systems and acoustic remote sensing.

John Pyle (University of Cambridge) reviewed chemical aspects for both the troposphere and stratosphere, with emphasis on ozone, and tropospheric OH (important in controlling methane and HCFCs). Results in the troposphere from some chemical models were compared with observations. Various chemical processes influencing ozone concentrations were described, with emphasis on the lower stratosphere, and wide disagreements between results from different models of these processes were highlighted. Measurement strategies were outlined for the troposphere and lower stratosphere, employing ground- and satellite-based systems.

The third session, on data management, was opened by Andrew Lorenc (Met. Office) who explained the role which methods of data assimilation will have in GCOS. At any one time, observations are always insufficient to determine the state of the atmosphere or ocean. The prediction models provide an evolution with time, allowing data distributed in time to be used with them; assimilation in four dimensions is the process of finding the model representation most consistent with the observations, using these data to modify the model state in a statistically optimal way. He described various uses for assimilation in GCOS, and the ways in which assimilation might be organized, such as in near real-time (when resources might be shared with numerical weather prediction), or in delayed mode (when the penalty of some duplication of effort is compensated for by more time to

collect and process observations). Among the advantages of assimilation he listed obtaining a consistent picture from disparate observations, getting more detail than from observations alone, and providing consistent derived fields from the physical understanding incorporated in the models.

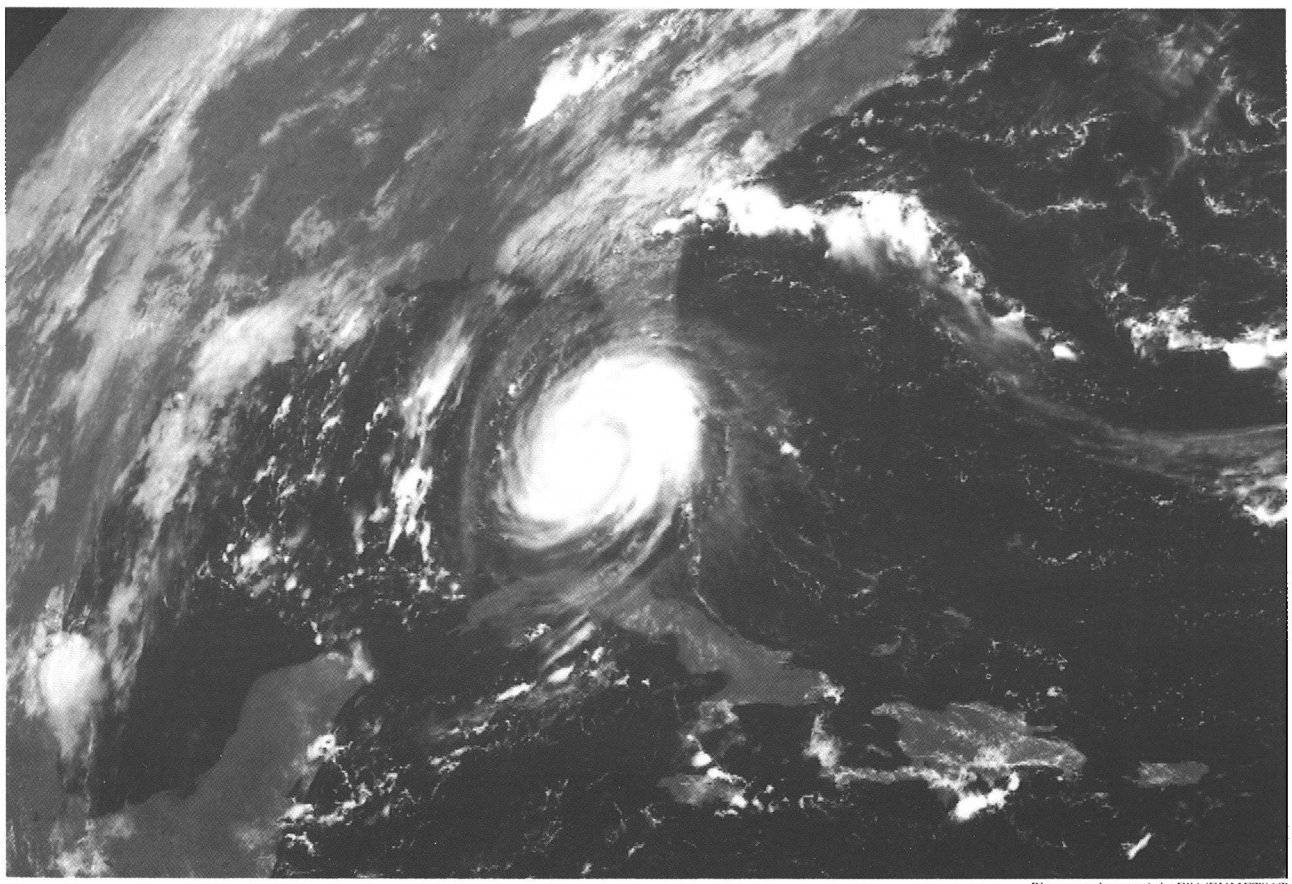
Crucial to the success of GCOS is the operational management of the data which it will produce. Peter Ryder (Met. Office) summarized the particular characteristics of its data such as exceptionally large volumes, diversity of types and sources, and large numbers of users, and explained the consequences; for example there will have to be much real-time processing and exchange, building on existing operational facilities, a systematic standardized approach, and significant investment. He sketched the data management components and summarized aspects of the system which GCOS mirrors in many respects and will be largely developed from — the World Weather Watch. He emphasized deficiencies needing to be corrected in this to cope with the substantial increase in throughput, such as under-investment in the satellite ground segment, the gulf between the space industry and users, and incomplete policy for data distribution.

In the penultimate session Alan Apling (DoE) considered the UK response to funding GCOS, from DoE's perspective. That Department is understandably cautious at this stage. There are no problems in drawing DoE in if the key to GCOS is climate change induced by human activities, and potentially controllable; but GCOS is also concerned with climate *per se*, in which many departments have an interest. The case for GCOS must be well substantiated. The key issues are: what are the deliverables? what are the benefits? The setting up of an intergovernmental committee has been an important step in the quest for funding. Very important here is to understand the long-term costs completely — there must be no surprises in a few years time! While many things are going GCOS's way at present, the crucial questions, on deliverables and objectives, need to be answered with great clarity when presenting the case.

The final talk was by Sir John, summarizing the present status of GCOS, and looking at the way forward. GCOS is needed to detect climate change as early as possible, and to validate and improve models. This will require better measurements of temperature, and other parameters. The international organization of GCOS is already well under way, with four sponsoring agencies, a Joint Scientific and Technical Committee (JSTC), and a Joint Planning Office in Geneva. The main functions and tasks of JSTC have been agreed. A good draft of the GCOS plan is required by the end of 1992, with assistance from people involved in WWW, GOOS, GAW (Global Atmospheric Watch), WCRP and CEOS (Committee on Earth Observation Satellites). The challenge is the precise definition of requirements. The core of GCOS is operational, and we have to work as far as possible through existing operational systems as well as research programmes. We have to recognize the world of difference between a research and an operational programme — the effort for the latter is consistently underestimated. Some of the TOGA measurements have to be continued to support GCOS. The problems of dealing with the huge quantities of data from the space component have to be addressed. Resources will have to come from national and international agencies as they do for WWW, from National Meteorological Services and space organizations for example. The intergovernmental meeting in April 1993 has important decisions to make here. Universal support, however modest (e.g. from some developing countries) is needed for GCOS to succeed. In the United Kingdom the key players will be the Met. Office, DoE, BNSC and the Research Councils, and they have to be on stage and working together. The Met. Office will have a key role because of its operational capabilities. DoE's clear interest is very welcome, though the line it is apparently drawing between natural, and human-induced, variability is a bit worrying. The space component is crucial, and the Research councils have a clear role also. One looks for growth in the Research Councils and Universities to undertake the many new studies which GCOS will require.

N. Thompson

NOAA use European satellite data during hurricane Andrew



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Meteosat visible image for 1455 UTC on 24 August 1992 as Andrew crosses Florida.

During 'Andrew's' lifetime, a combination of GOES and Meteosat images were used to monitor the cyclone at NOAA's National Hurricane Center (NHC) and Synoptic Analysis Branch (SAB) located in the NOAA National Environmental Satellite, Data, and Information Service (NESDIS). Using visible and infrared satellite imagery, both facilities analyse cloud patterns and overall organization (i.e. spiral bands, central dense overcast, eye pattern, etc.) to determine the location and intensity of tropical cyclones (these location/intensity estimates are termed 'classifications').

From 12 August to 14 August 1992, Andrew was tracked as an incipient disturbance over western Africa and the adjacent coastal waters. Meteosat-4 imagery was used exclusively during this stage.

Beginning on 15 August, the system began organizing over the open Atlantic south of the Cape Verde Islands, near latitude 9° N, longitude 22° W. Based upon Meteosat-3 data, NHC began preparing location and intensity estimates at 15/0000 UTC using infrared imagery; SAB began classifying the system at 15/1200 UTC using visible imagery.

Based exclusively on the systems organization depicted in Meteosat-3 imagery, the National Hurricane Center issued the first advisory for Tropical Depression 3 at 17/0300 UTC near latitude 11° N, longitude 38° W.

The system was upgraded to Tropical Storm Andrew at 17/1500 UTC near latitude 13° N, longitude 43° W, based on satellite classifications using Meteosat-3 visible/infrared imagery. Meteosat-3 water vapour imagery was used to track a strong upper-level cyclonic circulation north of Andrew; NHC forecast a period of 'slow development' based on this imagery and numerical model forecasts. Air Force Reserve reconnaissance aircraft began cyclone penetration on 19 August. Meteosat-3 continued to be the primary source of satellite imagery through 22/0000 UTC.

As Andrew crossed longitude 66° W (on 22/0000 UTC), the system entered the usable GOES-7 field of view (Meteosat-3 became a vital back-up data source). The system was upgraded to hurricane intensity at 22/0900 UTC near latitude 25.8° N, longitude 67.5° W. The hurricane attained sustained winds of at least 130 knots and a minimum central pressure of 922 hPa at 23/1800 UTC (this was at least a strong Category 4 hurricane on the Saffir–Simpson 1 to 5 scale). The hurricane crossed the Florida coast at about 24/0830 UTC and struck Louisiana at about 26/0730 UTC with sustained winds near 120 knots.

M. Phillips

GUIDE TO AUTHORS

Content

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December 1992

Edited by R.M. Blackall
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ISSN 0026—1149

Printed in the United Kingdom for HMSO Dd 291241, 1/93, C13, 543, 24503